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Adam , J , Brucken , E J , Chang , B , Kim , D J , Mieskolainen , M M , Orava , R , Rak , J , Räsänen , S S , Snellman , T W , Trzaska , W H , Viinikainen , J & The ALICE Collaboration
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2017 , no. 07 , 052 . https://doi.org/10.1007/JHEP07(2017)052

http://hdl.handle.net/10138/212994
https://doi.org/10.1007/JHEP07(2017)052

Published for SISSA by Springer

Received: *September 27, 2016*
Revised: *May 8, 2017*
Accepted: *June 17, 2017*
Published: *July 11, 2017*

Measurement of electrons from beauty-hadron decays in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV

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Abstract: The production of beauty hadrons was measured via semi-leptonic decays at mid-rapidity with the ALICE detector at the LHC in the transverse momentum interval $1 < p_{\mathrm{T}} < 8$ GeV/c in minimum-bias p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and in $1.3 < p_{\mathrm{T}} < 8$ GeV/c in the 20% most central Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. The pp reference spectra at $\sqrt{s} = 5.02$ TeV and $\sqrt{s} = 2.76$ TeV, needed for the calculation of the nuclear modification factors R_{pPb} and R_{PbPb}, were obtained by a pQCD-driven scaling of the cross section of electrons from beauty-hadron decays measured at $\sqrt{s} = 7$ TeV. In the p_{T} interval $3 < p_{\mathrm{T}} < 8$ GeV/c, a suppression of the yield of electrons from beauty-hadron decays is observed in Pb-Pb compared to pp collisions. Towards lower p_{T}, the R_{PbPb} values increase with large systematic uncertainties. The R_{pPb} is consistent with unity within systematic uncertainties and is well described by theoretical calculations that include cold nuclear matter effects in p-Pb collisions. The measured R_{pPb} and these calculations indicate that cold nuclear matter effects are small at high transverse momentum also in Pb-Pb collisions. Therefore, the observed reduction of R_{PbPb} below unity at high p_{T} may be ascribed to an effect of the hot and dense medium formed in Pb-Pb collisions.

Keywords: Heavy Ion Experiments

ArXiv ePrint: 1609.03898

https://doi.org/10.1007/JHEP07(2017)052

JHEP07(2017)052

Contents

1 Introduction

In collisions of heavy nuclei at ultra-relativistic energies, a high-density colour-deconfined state of strongly-interacting matter, called Quark-Gluon Plasma (QGP), is expected to be produced [1, 2]. Due to their large masses ($m_{\mathrm{Q}} \gg \Lambda_{\mathrm{QCD}}$), heavy quarks (charm and beauty) are almost exclusively produced in the early stage of the collision via hard parton scatterings characterised by production-time scales of less than 0.1 and 0.01 fm/c for charm and beauty quarks, respectively [3]. They can, therefore, serve as probes to test the mechanisms of medium-induced parton energy loss, because the formation time of the QGP medium is expected to be about 0.3 fm/c [4] and its decoupling time is about 10 fm/c for collisions at LHC energies [5]. Due to their stronger colour coupling to the medium gluons are argued to lose more energy than quarks [6–8]. Furthermore, the radiative energy loss of heavy quarks is predicted to be reduced with respect to light quarks due to the mass-dependent restriction of the phase space into which medium-induced gluon radiation can take place (dead-cone effect) [9–12]. The effect of the charm-quark mass on energy loss becomes negligible at high transverse momentum, $p_{\mathrm{T}} \gtrsim 10$ GeV/c, where the ratio $m_{\mathrm{c}}/p_{\mathrm{T}}$ approaches zero [13]. Therefore, due to the larger mass, beauty quarks can be sensitive probes for testing the mass dependence of the parton energy loss up to transverse momenta well above 10 GeV/c [13]. Final-state effects, such as colour-charge and mass dependence of parton energy loss, can be studied experimentally through the spectra of hadrons containing heavy quarks in comparison with light-flavour hadrons in heavy-ion (AA) collisions.

The understanding of final-state effects requires measurements of initial-state effects in Cold Nuclear Matter (CNM), which are inherent to nuclei in the collision system and thus present in AA collisions. Measurements in proton-nucleus (p-A) collisions are used to investigate cold nuclear matter effects such as the modification of the Parton Distribution Functions (PDF) inside the nucleus with respect to those in the proton, $k_{\rm T}$ broadening via parton collisions inside the nucleus prior to the hard scattering and energy loss in cold nuclear matter [14–18]. The effects of hot (cold) nuclear matter can be studied using the nuclear modification factor, $R_{\rm AA}$ ($R_{\rm pA}$), defined as the ratio of the $p_{\rm T}$ distributions measured in AA (p-A) collisions with respect to the one in pp collisions:

$$R_{\rm AA} = \frac{1}{\langle T_{AA}\rangle} \frac{{\rm d}N_{\rm AA}/{\rm d}p_{\rm T}}{{\rm d}\sigma_{\rm pp}/{\rm d}p_{\rm T}}, \tag{1.1}$$

where ${\rm d}N_{\rm AA}/{\rm d}p_{\rm T}$ and ${\rm d}\sigma_{\rm pp}/{\rm d}p_{\rm T}$ are the $p_{\rm T}$-differential yield and production cross section of a given particle species in AA and pp collisions, respectively, and $\langle T_{\rm AA}\rangle$ is the average of the nuclear overlap function for the centrality range under study [19].

Previous beauty-hadron production measurements in pp collisions at various energies at RHIC [20, 21], the Tevatron [22] and the LHC [3, 23–28] are described by Fixed Order plus Next-to-Leading-Log perturbative Quantum Chromodynamics (FONLL pQCD) calculations [29–31] within uncertainties.

At both RHIC and the LHC, a suppression of the yield of D mesons and high-$p_{\rm T}$ electrons and muons from heavy-flavour hadron decays was observed in AA collisions. The suppression is nearly as large as that of light-flavour hadrons at high $p_{\rm T}$ [32–36]. The D meson and pion $R_{\rm PbPb}$ were found to be consistent within uncertainties and described by model calculations that include a colour-charge dependent energy loss [34, 37, 38]. However, in addition to energy loss, the nuclear modification factor is also influenced by e.g. the parton $p_{\rm T}$ spectrum and the fragmentation into hadrons [13, 39]. Furthermore, the nuclear modification factors $R_{\rm PbPb}$ of prompt D mesons and of J/ψ from B meson decays were compared in the $p_{\rm T}$ interval $8 < p_{\rm T} < 16$ GeV/c for D mesons and $6.5 < p_{\rm T} < 30$ GeV/c for J/ψ mesons in order to have a similar average $p_{\rm T}$ ($\approx$10 GeV/c) for the heavy hadrons [34, 40, 41]. This comparison with models indicates that charm quarks lose more energy than beauty quarks in this $p_{\rm T}$ interval in central Pb-Pb collisions. The b-jet yield as measured in Pb-Pb collisions also shows a suppression compared with the yield expected from pp collisions in the jet-$p_{\rm T}$ interval $70 < p_{\rm T} < 250$ GeV/c [42]. Recently, the relative contributions of electrons from charm- and beauty-hadron decays were measured as a function of transverse momentum in Au-Au collisions at RHIC [43]. There is a hint that in the momentum interval $3 < p_{\rm T} < 4$ GeV/c the $R_{\rm AuAu}$ of electrons from beauty-hadron decays is larger than that of electrons from charm-hadron decays.

In p-Pb collisions at the LHC, the nuclear modification factors of B mesons [44], b-jets [45], J/ψ from beauty-hadron decays [46, 47], leptons from heavy-flavour hadron decays and D mesons [48, 49] were investigated extensively. The results are consistent with unity within uncertainties and compatible with theoretical calculations including cold nuclear matter effects [45–48]. Therefore, the observed suppression of charm and beauty yields at high p_{T} in Pb-Pb collisions is not explained in terms of initial-state effects but is due to strong final-state effects induced by hot partonic matter.

In central d-Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200\,\mathrm{GeV}$ at RHIC, an enhancement was measured at backward rapidity by means of R_{dAu} of muons from heavy-flavour hadron decays [50]. Theoretical calculations including modified PDFs cannot describe the data, implying that models incorporating only initial-state effects are not sufficient and suggesting the possible importance of final-state effects in the d-Au collision system. Recently, a potential signature of collective behaviour in small systems was observed via the anisotropic flow parameter v_2 of charged hadrons in p-Pb collisions [51–54] and in d-Au collisions [55, 56], suggesting radial flow as a possible explanation of the enhancement of the R_{dAu} [57].

In this paper, the invariant cross section in p-Pb and yield in Pb-Pb collisions are presented together with the nuclear modification factors, R_{pPb} and R_{PbPb}, of electrons from beauty-hadron decays in p-Pb and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ and $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$, respectively. The identification of electrons from beauty-hadron decays is based on their separation from the interaction vertex, induced by the sizable lifetime of beauty hadrons. The p-Pb (Pb-Pb) measurement covers the rapidity range $|y_{\mathrm{lab}}| \leq 0.6$ ($|y_{\mathrm{lab}}| \leq 0.8$) and the p_{T} interval $1.0 < p_{\mathrm{T}} < 8.0$ GeV/c ($1.3 < p_{\mathrm{T}} < 8.0$ GeV/c). In the p-Pb collisions, due to the different energy per nucleon of the proton and lead beam, the centre-of-mass system (cms) is shifted by $\Delta y = 0.465$ in the proton beam direction, resulting in the rapidity coverage $-1.06 < y_{\mathrm{cms}} < 0.14$ for electrons. Given the cms energies and the rapidity coverages in the p-Pb and Pb-Pb collisions, both measurements probe, at the lowest p_{T}, similar values of Bjorken-x of about 10^{-3} for electrons from beauty-hadron decays [58]. The Pb-Pb measurement is restricted to the 20% most central Pb-Pb collisions, where the largest effect of energy loss on heavy-flavour production is expected.

The paper is organised as follows: section 2 describes the experimental apparatus and the data samples used in both analyses, which are outlined in section 3. Details of the analysis in p-Pb and Pb-Pb collisions are given in sections 4 and 5, respectively. The determination of the pp reference spectra for the calculations of the R_{pPb} and R_{PbPb} is reported in section 6. The results are presented and discussed in section 7. Section 8 summarises the results.

2 Experimental apparatus and data samples

A comprehensive description of the ALICE apparatus and its performance can be found in [59] and [60], respectively. Electron tracks were reconstructed and identified using detectors located inside the solenoid magnet that generates a field of 0.5 T parallel to the beam direction. Forward and backward detectors inside and outside the magnet were employed for triggering, background rejection and event characterisation.

Charged particles are tracked with the Inner Tracking System (ITS) [59, 61] and the Time Projection Chamber (TPC) [62] in the pseudorapidity range $|\eta| < 0.9$. The ITS consists of six cylindrical layers of silicon detectors. The two innermost layers are made of Silicon Pixel Detectors (SPD), the two middle layers of Silicon Drift Detectors (SDD) and the two outermost layers of Silicon Strip Detectors (SSD). In the direction perpendicular to the detector surface, the total material budget of the ITS corresponds on average to 7.7% of a radiation length [61]. In this analysis, the ITS was also used to reconstruct the primary (interaction) vertex and the track impact parameter d_0, defined as the distance of closest approach of the track to the interaction vertex in the plane transverse to the beam direction. The resolution on d_0 is better than 65 μm and 70 μm for charged particles with momenta larger than 1 GeV/c in Pb-Pb and p-Pb collisions [60], respectively, including the resolution of the primary vertex determination. The particle identification capability of the four outer layers of the ITS via the measurement of the ionisation energy loss $\mathrm{d}E/\mathrm{d}x$ was used at low transverse momentum in the p-Pb analysis. The TPC, which provides up to 159 space points per track, is used for particle identification via the measurement of the specific energy loss $\mathrm{d}E/\mathrm{d}x$ in the detector gas. The tracks reconstructed in the ITS and the TPC are matched to hits in the other detectors inside the magnet located at larger radii. The Transition Radiation Detector (TRD) [63] surrounding the TPC provides hadron and electron identification via the measurement of the specific energy loss $\mathrm{d}E/\mathrm{d}x$ and transition radiation. During the Pb-Pb (p-Pb) data taking period it covered 7/18 (13/18) of the full azimuth. Therefore, only in the Pb-Pb analysis it was used to verify the amount of hadron contamination within the electron identification strategy at low transverse momentum (see section 5). The Time-Of-Flight array (TOF) [64], based on Multi-gap Resistive Plate Chambers (MRPCs), provides hadron rejection at low transverse momentum via the time-of-flight measurement, within the electron identification strategy applied in both analyses. The T0 detectors, arrays of Cherenkov counters, located at +350 cm and −70 cm from the interaction point along the beam direction [65] provided, together with the TOF detector, the precise start time for the time-of-flight measurement in the p-Pb analysis. For central Pb-Pb events the start time was estimated only using the particle arrival times at the TOF detector.

The SPD, the T0 detectors as well as the V0 scintillator arrays, placed on both sides of the interaction point at $2.8 < \eta < 5.1$ (V0-A) and $-3.7 < \eta < -1.7$ (V0-C), respectively, can be employed to define a minimum-bias trigger. The two Zero Degree Calorimeters (ZDC), that are symmetrically located 112.5 m from the interaction point on either side, were used in the offline event selection to reject beam-gas interactions by correlating the time information with the one from the V0 detectors.

The Pb-Pb and p-Pb data presented here were recorded in 2010 and 2013, respectively. Minimum-bias p-Pb collisions were selected by requiring coincident signals in V0-A and V0-C (V0AND condition). Beam-gas interactions were rejected offline by the aforementioned correlation of the ZDC and V0 time information. The Pb-Pb collisions were collected with two different minimum-bias interaction triggers. The first trigger condition required signals in two of the following three detectors: SPD (two hits in the outer SPD layer), V0-A and V0-C. The second trigger condition required a coincidence between V0-A and V0-C. Both minimum-bias trigger conditions had efficiencies larger than 95% for hadronic interactions, whereas the second rejected electromagnetic processes to a large extent [66]. Only events with a primary vertex within ± 10 cm from the centre of the detector along the beam direction were considered in the p-Pb and Pb-Pb analyses. The Pb-Pb events were categorised into centrality classes by fitting the sum of the two V0 signal amplitudes with a geometrical Glauber-model simulation [19], as described in [66]. The Glauber-model simulation yields a value of 18.93 ± 0.74 mb^{-1} for the average nuclear overlap function $\langle T_{\mathrm{AA}} \rangle$ for the 20% most central Pb-Pb collisions considered in the analysis. About 100 and 3 million p-Pb and 20% most central Pb-Pb events passed the offline selection criteria corresponding to an integrated luminosity of $L_{\mathrm{int}}^{\mathrm{pPb}} = 47.8 \pm 1.6\ \mu\mathrm{b}^{-1}$ and $L_{\mathrm{int}}^{\mathrm{PbPb}} = 2.2 \pm 0.2\ \mu\mathrm{b}^{-1}$, respectively.

3 Analysis overview and electrons from background sources

The identification of electrons from beauty-hadron decays is divided into the following steps:

- selection of tracks with good quality,
- electron identification (eID),
- determination of the electron yield from beauty-hadron decays.

The signal contains both electrons from direct decays (b → e, branching ratio: ≈11%) as well as cascade decays (b → c → e, branching ratio: ≈10%) of hadrons that contain a beauty (or anti-beauty) quark [67]. Throughout the paper the term 'electron' denotes both electron and positron. The track selection procedure is identical to previous analyses on the production of electrons from beauty-hadron decays [23, 24]. The selection criteria are the same in the p-Pb and Pb-Pb analyses, except for the restriction of the geometrical acceptance in rapidity, which was adjusted in each collision system to the region where the TPC could provide optimal electron identification, taking into account the detector and running conditions during each data-taking period. In Pb-Pb collisions this corresponds to the rapidity range $|y_{\mathrm{lab}}| \leq 0.8$ and in p-Pb to $|y_{\mathrm{lab}}| \leq 0.6$. The tracks were required to have associated hits in both SPD layers, in order to minimise the contribution of electrons from photon conversions in the ITS detector material and the fraction of tracks with misassociated hits (see below).

The electrons were identified with the TPC and the TOF detectors via the measurement of their respective signal, specific energy loss in the gas ($\mathrm{d}E/\mathrm{d}x$) and the time-of-flight. The selection variable (hereafter n_σ^{TPC} or n_σ^{TOF}) is defined as the deviation of the measured signal of a track with respect to the expected signal for an electron in units of the corresponding detector resolution (σ_{TPC} or σ_{TOF}). The expected signal and the resolution originate from parametrisations of the TPC and TOF detector signals, described in detail in [60]. For both analyses, particles were accepted with the TPC as electron candidates if they satisfied the condition $-0.5 < n_\sigma^{\mathrm{TPC}} < 3$. This asymmetric selection was chosen to remove hadrons, that are mainly found at negative n_σ^{TPC} values. However, at low and high transverse momentum, the eID strategy based on TPC is subject to contamination from pions, kaons, protons and deuterons. To resolve these ambiguities, a selection cut of $|n_\sigma^{\mathrm{TOF}}| \leq 3$ was applied for the whole p_{T} range in the Pb-Pb analysis and for p_{T}

≤ 2.5 GeV/c in the p-Pb analysis. The remaining hadron contamination was determined via data-driven methods in the p-Pb analysis and subtracted statistically (see section 4). The technique used for the Pb-Pb analysis is described in section 5.

The electrons passing the track and eID selection criteria originate, besides from beauty-hadron decays, from the following background sources. In what follows, prompt and non-prompt contributions are marked in parentheses as 'P' and 'NP', respectively:

- (P) Dalitz and di-electron decays of prompt light neutral mesons ($\pi^0, \eta, \rho, \omega, \eta', \phi$),
- (P) di-electron decays of prompt heavy quarkonia (J/ψ, etc.).
- (NP) decay chains of hadrons carrying a strange (or anti-strange) quark,
- (NP) photon conversions in the detector material,
- (NP) semi-leptonic decays of prompt hadrons carrying a charm (or anti-charm) quark.

The measurement of the production of electrons from beauty-hadron decays exploits their larger mean proper decay length ($c\tau \approx 500$ μm [67]) compared to that of charm hadrons and most other background sources, resulting in a larger average impact parameter. The sign of the impact parameter value is attributed based on the relative position of the track and the primary vertex, i.e. if the primary vertex lies on the left- or right-hand side of the track with respect to the particle momentum direction in the transverse plane.

For the presented analyses, the impact parameter was multiplied with the sign of the particle charge and of the magnetic field component along the beam axis (plus or minus for the two field orientations). With this definition, the sign of the impact parameter depends on whether the primary vertex lies inside or outside of the circle defined by the track projection in the transverse plane. Electrons from the conversion of photons in the detector material have an initial momentum with a very small angle to the direction of the photon. The magnetic field bends the track away from the primary vertex. Thus, they typically have an impact parameter $d_0 < 0$. The asymmetric shape helps to differentiate this background source. It is important to include the field configuration, because the magnetic field direction was reversed during the Pb-Pb data taking period, which motivated this redefinition.

Figure 1 shows for two p_{T} intervals the resulting distribution of the measured impact parameter value multiplied by the sign of the charge of each track and the sign of the magnetic field in the 20% most central Pb-Pb collisions. The impact parameter distributions for electrons from beauty- and charm-hadron decays, from Dalitz decays of light mesons, and from photon conversions are also drawn for comparison. The distributions were obtained from Monte Carlo simulations and normalised to the data using the fit values described in section 5. The distribution for electrons from photon conversions is, as explained before, visible as an asymmetric and shifted distribution. The impact parameter distribution of electrons from prompt sources, such as Dalitz and quarkonium decays, is determined by the impact parameter resolution. The electrons from these sources are thus categorised as Dalitz decays within both analyses.

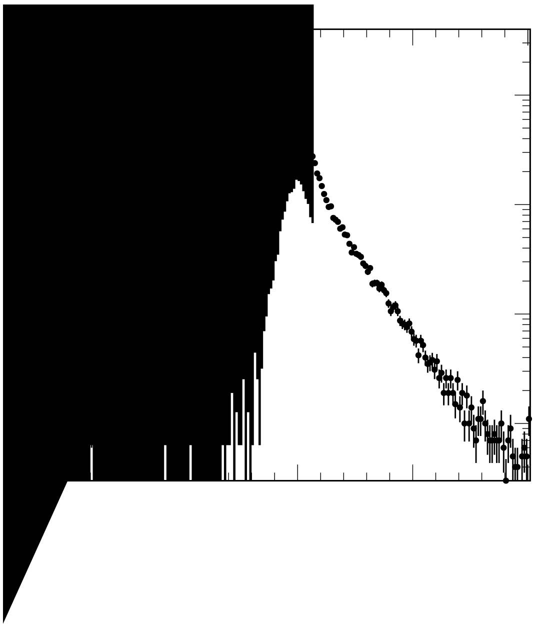

Figure 1. Impact parameter distribution for the interval (left) $1.5 < p_{\mathrm{T}} < 2.0$ GeV/c and (right) $5 < p_{\mathrm{T}} < 6$ GeV/c in the 20% most central Pb-Pb collisions. The impact parameter value of each track was multiplied by the sign of the charge of each track and the sign of the magnetic field. The individual distributions for electrons from beauty-hadron and charm-hadron decays, from Dalitz-decays of light mesons, and from photon conversions were obtained by HIJING and PYTHIA simulations. The bottom panel shows the ratio of the data and 'Sum'.

The Monte Carlo simulations were produced as follows. A sample of minimum-bias Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV was generated with HIJING v1.36 [68] for efficiency and acceptance corrections as well as to obtain the impact parameter distributions for photon conversions and Dalitz decays. To increase the statistics of electrons from charm- and beauty-hadron decays, a signal enhanced sample was generated using pp events produced by the generator PYTHIA v6.4.21 [69] with Perugia-0 tune [70]. Each added pp event contains one $c\bar{c}$ or $b\bar{b}$ pair. For the p-Pb analysis, the same procedure was used. The generated particles were propagated through the ALICE apparatus using GEANT3 [71] and a realistic detector response was applied to reproduce the performance of the detector system during data taking.

The inclusive yield of electrons originating from strange-hadron decays is small compared to the other background sources. However, as these electrons originate from secondary π^0 from strange-hadron decays ($\mathrm{K}^0_{\mathrm{S}}$, $\mathrm{K}^0_{\mathrm{L}}$, $\mathrm{K}^{\pm}$, Λ) and three prong decays of strange hadrons ($\mathrm{K}^0_{\mathrm{L}}$,$\mathrm{K}^{\pm}$), the impact parameter distribution is broader than that of electrons from Dalitz and di-electron decays of other light neutral mesons. Sections 4 and 5 describe how the analyses handle this background contribution.

Although requiring hits in both SPD layers, electrons from photon conversions in detector material with production radii outside the SPD layers were observed to have passed the track selection. These electron tracks are wrongly associated with signals of other particles in the inner detector layers. Within this paper these electrons are called

pp spectrum 7 TeV	45% to 35% for $1 < p_{\rm T} < 1.5$ GeV/c 35% to 20% for $1.5 < p_{\rm T} < 2.5$ GeV/c $\leq 20\%$ for $p_{\rm T} \geq 2.5$ GeV/c	
Normalisation uncertainty	3.5%	
scaling uncertainty for	p-Pb ($\sqrt{s} = 5.02$ TeV)	Pb-Pb ($\sqrt{s} = 2.76$ TeV)
at $p_{\rm T} = 1$ GeV/c	$^{+4}_{-2}\%$	$^{+11}_{-\ 7}\%$
at $p_{\rm T} = 8$ GeV/c	$^{+2}_{-2}\%$	$^{+7}_{-5}\%$

Table 3. Systematic uncertainties of the $p_{\rm T}$-differential cross section of electrons from beauty-hadron decays measured at $\sqrt{s} = 7$ TeV [23], the normalisation uncertainty, as well as the scaling uncertainties for the reference spectra at $\sqrt{s} = 5.02$ TeV and $\sqrt{s} = 2.76$ TeV. The scaling uncertainties for the reference spectra are slightly $p_{\rm T}$ dependent; the uncertainties are given for the two extreme $p_{\rm T}$ intervals. Details are described in the text.

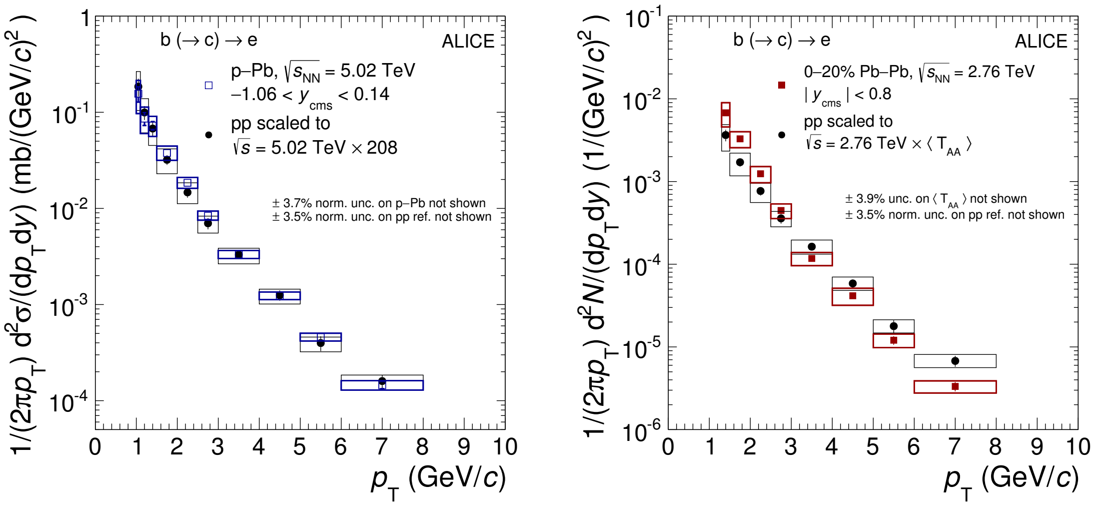

Figure 5. Invariant cross section (left) and yield (right) of electrons from beauty-hadron decays as a function of transverse momentum in minimum-bias p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV and in the 20% most central Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. The pp reference spectra scaled by the number of nucleons in the Pb nucleus (A = 208) and by $\langle T_{\rm AA}\rangle$, respectively, are shown as well. The vertical bars represent the statistical uncertainties, the boxes indicate the systematic uncertainties. The pp and p-Pb normalisation uncertainties of 3.5% and 3.7% as well as the one of the nuclear overlap function $\langle T_{\rm AA}\rangle$ of 3.9% are not shown.

7 Results

The $p_{\rm T}$-differential cross section and invariant yield of electrons from beauty-hadron decays at mid-rapidity in minimum-bias p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV and in the 20% most central Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV, respectively, are shown in figure 5. The markers are plotted at the centre of the $p_{\rm T}$ bin. The vertical bars indicate the statistical uncertainties, the boxes represent the systematic uncertainties. The pp reference spectra, obtained via the pQCD-driven $\sqrt{s}$-scaling from the measurement in pp collisions

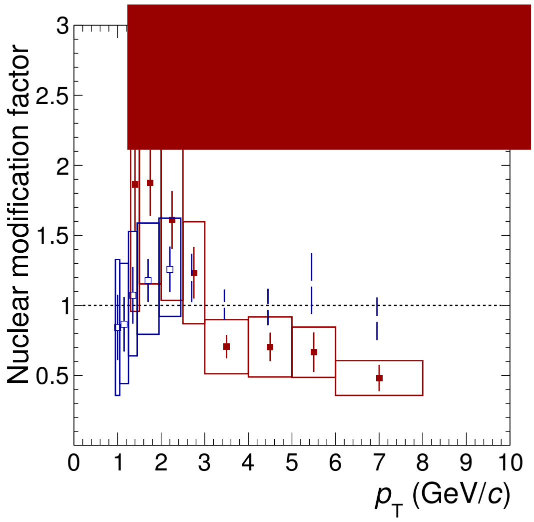

Figure 6. (Left) Nuclear modification factors R_{pPb} and R_{PbPb} of electrons from beauty-hadron decays at mid-rapidity as a function of transverse momentum for minimum-bias p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ and 20% most central Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$. The data points of the p-Pb analysis were shifted by 0.05 GeV/c to the left along the p_{T} axis for better visibility. (Right) R_{PbPb} of electrons from beauty-hadron decays together with the corresponding result for beauty- and charm-hadron decays [89] for the 20% most central Pb-Pb collisions. The vertical bars represent the statistical uncertainties, while the boxes indicate the systematic uncertainties. The normalisation uncertainties, common to all points, are shown as filled boxes at high p_{T} for all nuclear modification factors.

at $\sqrt{s} = 7\,\mathrm{TeV}$ as described in section 6, are shown for comparison. The pp reference spectra were multiplied by the number of nucleons in the Pb nucleus (A = 208) for the p-Pb and with the nuclear overlap function ($\langle T_{\mathrm{AA}}\rangle$) for the Pb-Pb comparison. The Pb-Pb result shows a suppression of electrons from beauty-hadron decays at high p_{T} compared to the yield in pp collisions. Such a suppression is not seen in the comparison of the p-Pb spectrum with the corresponding pp reference.

The nuclear modification factors R_{PbPb} and R_{pPb} are shown in figure 6 (left). The R_{PbPb} was obtained using equation (1.1). The R_{pPb} was calculated as the ratio of the cross section of electrons from beauty-hadron decays in p-Pb and pp collisions scaled by the number of nucleons in the Pb nucleus (A = 208). The statistical and systematic uncertainties of the Pb-Pb or p-Pb and the pp spectra were propagated as independent uncertainties. The systematic uncertainties of the nuclear modification factors are partially correlated between the p_{T} bins. The normalisation uncertainty of the pp spectrum and the uncertainty of the nuclear overlap function $\langle T_{\mathrm{AA}}\rangle$ or the normalisation uncertainties of the p-Pb spectrum, respectively, were added in quadrature. The normalisation uncertainties are shown as filled boxes at high transverse momentum in figure 6.

The R_{pPb} is consistent with unity within uncertainties (of about 20% for $p_{\mathrm{T}} > 2$ GeV/c) for all shown transverse momenta. The production of electrons from beauty-hadron decays is thus consistent with binary-collision scaling of the corresponding measurement in pp collisions at the same centre-of-mass energy. The values of the R_{PbPb} for the 20% most

EPS09 modifications of the PDFs and describes the medium using an underlying hydrodynamical model. The transport coefficients used for the evolution of the heavy quark in the medium are either extracted from lattice-QCD calculations or Hard-Thermal-Loop (HTL) resummation [101] of medium effects. The hadronisation via in-vacuum fragmentation functions or via in-medium string-fragmentation routines occurs once the decoupling temperature is reached. The calculations are shown for different transport coefficients with a decoupling temperature $T_{\mathrm{dec}} = 155\,\mathrm{MeV}$; the results with a temperature of $T_{\mathrm{dec}} = 170\,\mathrm{MeV}$ look similar. No scenario is clearly favoured by the current data set. The AdS/CFT model, which includes energy loss fluctuations in a realistic strong-coupling energy loss mode, clearly shows a stronger suppression than the measured R_{PbPb}.

The MC@sHQ+EPOS2, the BAMPS as well as the TAMU calculation describe the suppression seen in data at high transverse momentum. They also show an increase towards lower momentum reaching R_{PbPb} values around unity or slightly above. The data show a larger increase with decreasing transverse momentum, however exhibit large systematic and statistical uncertainties.

8 Summary

The p_{T}-differential cross section and invariant yield of electrons from beauty-hadron decays in minimum-bias p-Pb collisions and in the 20% most central Pb-Pb collisions, respectively, were measured at mid-rapidity. The measurements are compared via the nuclear modification factors with pp reference spectra, obtained by a pQCD-driven $\sqrt{s}$-scaling of the cross section of electrons from beauty-hadron decays measured at $\sqrt{s} = 7\,\mathrm{TeV}$. The R_{pPb} is consistent with unity within uncertainties of about 20% at high transverse momentum p_{T}, which increase towards low p_{T}. The R_{pPb} is described by pQCD calculations including initial-state effects, energy loss approaches as well as by a blast wave model calculation that parametrises possible hydrodynamic effects. The R_{PbPb} is about 0.7 with an uncertainty of about 30% in the interval $3 < p_{\mathrm{T}} < 6$ GeV/c and 0.48 with an uncertainty of about 25% for $6 < p_{\mathrm{T}} < 8$ GeV/c. The suppression seen in the higher transverse momentum interval is not described by pQCD calculations including only initial-state effects, indicating a final-state effect as the origin. The values of the R_{PbPb} increase for $p_{\mathrm{T}} \leq 3$ GeV/c with uncertainties of about 30–45%. The measured R_{PbPb} is described within uncertainties by pQCD-inspired models of beauty-quark energy loss in the QGP. In the interval $3 < p_{\mathrm{T}} < 6$ GeV/c, we observe that the suppression of the R_{PbPb} for electrons from beauty-hadron decays is about 1.2σ less than that from charm- and beauty-hadron decays. This difference is consistent with the ordering of charm and beauty suppression seen in the prompt D meson and J/ψ from B meson comparison.

Acknowledgments

The ALICE Collaboration would like to thank all its engineers and technicians for their invaluable contributions to the construction of the experiment and the CERN accelerator teams for the outstanding performance of the LHC complex. The ALICE Collaboration gratefully acknowledges the resources and support provided by all Grid centres and the Worldwide LHC Computing Grid (WLCG) collaboration. The ALICE Collaboration acknowledges the following funding agencies for their support in building and running the ALICE detector: A. I. Alikhanyan National Science Laboratory (Yerevan Physics Institute) Foundation (ANSL), State Committee of Science and World Federation of Scientists (WFS), Armenia; Austrian Academy of Sciences and Nationalstiftung für Forschung, Technologie und Entwicklung, Austria; Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Financiadora de Estudos e Projetos (Finep) and Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil; Ministry of Education of China (MOE of China), Ministry of Science & Technology of China (MOST of China) and National Natural Science Foundation of China (NSFC), China; Ministry of Science, Education and Sport and Croatian Science Foundation, Croatia; Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), Cuba; Ministry of Education, Youth and Sports of the Czech Republic, Czech Republic; Danish National Research Foundation (DNRF), The Carlsberg Foundation and The Danish Council for Independent Research — Natural Sciences, Denmark; Helsinki Institute of Physics (HIP), Finland; Commissariat à l'Energie Atomique (CEA) and Institut National de Physique Nucléaire et de Physique des Particules (IN2P3) and Centre National de la Recherche Scientifique (CNRS), France; Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF) and GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany; Ministry of Education, Research and Religious Affairs, Greece; National Research, Development and Innovation Office, Hungary; Department of Atomic Energy Government of India (DAE), India; Indonesian Institute of Science, Indonesia; Centro Fermi - Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi and Istituto Nazionale di Fisica Nucleare (INFN), Italy; Institute for Innovative Science and Technology , Nagasaki Institute of Applied Science (IIST), Japan Society for the Promotion of Science (JSPS) KAKENHI and Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan; Consejo Nacional de Ciencia (CONACYT) y Tecnología, through Fondo de Cooperación Internacional en Ciencia y Tecnología (FONCICYT) and Dirección General de Asuntos del Personal Academico (DGAPA), Mexico; Nationaal instituut voor subatomaire fysica (Nikhef), Netherlands; The Research Council of Norway, Norway; Commission on Science and Technology for Sustainable Development in the South (COMSATS), Pakistan; Pontificia Universidad Católica del Perú, Peru; Ministry of Science and Higher Education and National Science Centre, Poland; Ministry of Education and Scientific Research, Institute of Atomic Physics and Romanian National Agency for Science, Technology and Innovation, Romania; Joint Institute for Nuclear Research (JINR), Ministry of Education and Science of the Russian Federation and National Research Centre Kurchatov Institute, Russia; Ministry of Education, Science, Research and Sport of the Slovak Republic, Slovakia; National Research Foundation of South Africa, South Africa; Korea Institute of Science and Technology Information and National Research Foundation of Korea (NRF), South Korea; Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) and Ministerio de Ciencia e Innovacion, Spain; Knut & Alice Wallenberg Foundation (KAW) and Swedish Research Council (VR), Sweden; European

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Organization for Nuclear Research, Switzerland; National Science and Technology Development Agency (NSDTA), Office of the Higher Education Commission under NRU project of Thailand and Suranaree University of Technology (SUT), Thailand; Turkish Atomic Energy Agency (TAEK), Turkey; National Academy of Sciences of Ukraine, Ukraine; Science and Technology Facilities Council (STFC), United Kingdom; National Science Foundation of the United States of America (NSF) and United States Department of Energy, Office of Nuclear Physics (DOE NP), United States.

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